

NANOMATERIALS IN MAINTENANCE WORK: OCCUPATIONAL RISKS AND PREVENTION

The field of nanotechnology is advancing rapidly and the use of nanomaterials is becoming more common in both our daily lives and our workplaces. This means that more workers performing maintenance work could be exposed to nanomaterials. Despite ongoing research, the field of nanotechnology is developing faster than the generation of knowledge on the health and safety effects of nanomaterials. There are still many unknowns, which raises questions concerning the evaluation of occupational safety and health (OSH) risks.

This e-fact explains how workers could come across nanomaterials when undertaking maintenance work and provides information on what should be done to prevent potential exposures.

1 Introduction

1.1 What are nanomaterials?

Nanomaterials are materials containing particles with one or more dimension between 1 and 100 nm⁽¹⁾, a scale comparable to atoms and molecules. They may be natural, such as from volcano ashes, or an unintended consequence of human activities, such as those contained in diesel exhaust fumes. However, a large number of nanomaterials are intentionally manufactured and placed on the market, and it is these that this e-fact focuses on.

Even though nanomaterials can form agglomerates or aggregates that can be larger than 100 nm, these can decompose and release nanomaterials. Therefore, these agglomerates/aggregates should also be considered in any nanomaterial risk assessment.

The specific (novel) properties of manufactured nanomaterials present many benefits for numerous applications. Manufactured nanomaterials can be used either on their own or in combination with other materials to achieve, for example:

1. miniaturisation (e.g. of electronic equipment);
2. weight reduction (as a result of an increased material efficiency); and
3. improved functionalities of materials (e.g. higher durability, conductivity, thermal stability, solubility, decreased friction).

The types of manufactured nanomaterials potentially present in workplaces depend on the types of processes carried out, the types of products produced and the materials used as input or as a processing aid.

⁽¹⁾ According to the European Commission's Recommendation [1]:

- A "nanomaterial" is "a natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm - 100 nm. The number size distribution is expressed as number of objects within a given size range divided by the number of objects in total."
- "In specific cases and where warranted by concerns for the environment, health, safety or competitiveness the number size distribution threshold of 50% may be replaced by a threshold between 1 and 50%."
- "By derogation from the above, fullerenes, graphene flakes and single wall carbon nanotubes with one or more external dimensions below 1 nm should be considered as nanomaterials."

1.2 Maintenance

Regular maintenance is essential to keep equipment, machines, buildings and structures (such as bridges or tunnels), as well as the work environment, safe and reliable. Maintenance work includes a variety of activities across very different sectors and types of working environments. It typically comprises servicing, repairing, inspecting, testing, adjusting or replacing parts and may involve, for example, opening closed production systems, exchanging filters, removing paint layers, blasting, grinding, sanding, applying fillers, applying paint, insulating, and repairing a power grid, gas supply or water supply. As maintenance is carried out to some extent in all sectors and workplaces, maintenance workers are more likely than other workers to be exposed to a broad range of occupational hazards.



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Maintenance can be proactive - to prevent machine or structure failures and unsafe workplace conditions - or reactive - to repair equipment or building modules. Maintenance activities can therefore be part of a worker's daily routine, for example cleaning and checking a spray gun at the end of a working day, or special activities carried out when equipment or machinery is not functioning properly. Maintenance work could be the main activity for construction workers.

Useful information on maintenance and OSH is available on EU-OSHA's website at <https://osha.europa.eu/en/topics/maintenance>.

1.3 Nanomaterials in maintenance work

Even though nanotechnology is a relatively new branch of industry, nanomaterials are already used in numerous applications for their specific properties. This means that possible exposure to nanomaterials during maintenance activities needs to be considered in an increasing number of sectors and workplaces.

Indeed, as the number of manufactured products containing nanomaterials increases, workers are more likely to be required to carry out maintenance work on such products and, possibly, to be exposed to nanomaterials. Examples of such products containing nanomaterials include automobiles, low-rolling resistance tyres, electrical and electronic equipment such as high-efficiency sensors and electronics, energy generation equipment such as high-power rechargeable battery systems or thin-film smart solar panels. Buildings themselves can also contain nanomaterials.

In addition, there is an increasing number of maintenance products on the market containing manufactured nanomaterials that are used to perform maintenance work, such as lubricants, coatings or adhesives. If adequate prevention measures are not in place, these may also result in the exposure of workers.

Certain applications of manufactured nanomaterials may also offer huge benefits to maintenance workers from an OSH point of view, for example smart paints used for the detection of cracks or corrosion in painted surfaces. Smart paints contain carbon nanotubes that conduct electricity. Their conductivity is affected by the presence of such defects on the surface, and therefore these paints may be used for the remote detection of microscopic structural problems, for instance in bridges or wind turbines, thus avoiding the need to work at height to check such structures.

2 OSH risks from nanomaterials to workers doing maintenance work

Although nanomaterials offer numerous benefits, some may be hazardous to human health and safety [2–4] and put maintenance workers at risk.

2.1 Hazards and exposure routes

Safety hazards may result from the high explosiveness, flammability and catalytic potential of some nanopowders (nanomaterials in powder form), particularly metal nanopowders.

Nanomaterials may have a wide range of potential toxic effects even if the same material at macro scale does not. This is mainly because of their small size, but also depends on particle shape, chemical nature, surface state (e.g. surface area, surface functionalisation, surface treatment), state of aggregation/agglomeration, etc. [3, 4].

Under normal environmental conditions, nanomaterials may form agglomerates or aggregates larger than 100 nm, thereby changing (but not necessarily losing) their nano-specific properties. However, nanomaterials may be released again from weakly bound agglomerates and, under certain conditions, even from more strongly bound aggregates. It is being investigated whether this could happen in lung fluid after inhalation of such agglomerates or aggregates [3, 4]. Agglomerates and aggregates containing nanomaterials should therefore also be taken into consideration in the workplace risk assessment.

The internal exposure mechanism, following the entry of nanomaterials into the body, could include further absorption, distribution and metabolism. Some nanomaterials were, for example, found in the lung, liver, kidneys, heart, reproductive organs, fetus, brain, spleen, skeleton and soft tissues [5]. There are open questions concerning the bioaccumulation of nanomaterials and elimination mechanisms from cells and organs. An additional issue is that, while a nanomaterial itself may not be toxic, it could act as a Trojan horse, meaning that a more toxic material may attach itself to the nanomaterial and gain entry to the body's organs or cells [6].

The most important effects of nanomaterials have been found in the lungs and include inflammation, tissue damage, oxidative stress, chronic toxicity, cytotoxicity, fibrosis and tumour generation. Some nanomaterials may also affect the cardiovascular system. The potentially hazardous properties of manufactured nanomaterials are a matter of ongoing research [3, 4].

Examples of nanomaterials to which maintenance workers may be exposed and their health hazards are presented in Table 1. These nanomaterials are particularly relevant to maintenance as they are used in paints, disinfectants, cleaning agents or other products commonly used for maintenance work.

Table 1: Examples of nanomaterials to which maintenance workers may be exposed and their potential health hazards

Type of nanomaterial	Health hazards
Silver nanoparticles	The use of silver nanoparticles represents a potential hazard to human health [8] and the EU Scientific Committee on Emerging and Newly Identified Health Risks was requested for a scientific opinion on the safety, health and environmental effects and role in antimicrobial resistance of nanosilver [9]. There are concerns that silver nanoparticles can cause adverse health effects, such as allergies [10], pulmonary oedemas [11], and argyria or argyrosis (i.e. grey or grey-blue discolouration or black pigmentation of the skin, nails, eyes, mucous membranes or internal organs by silver deposits), that cannot be reversed and are incurable [12]. It was also documented in rats that silver nanoparticles can reach the brain through the upper respiratory tract [13].

Type of nanomaterial	Health hazards
Titanium dioxide (TiO ₂) nanoparticles	Titanium dioxide particles, when inhaled, have been classified by the International Agency for Research on Cancer (IARC) as possibly carcinogenic to humans (Group 2B carcinogen) [14]. The US National Institute for Occupational Safety and Health (NIOSH) recommended a lower exposure limit for ultrafine particles of TiO ₂ : 0.3 mg/m ³ for TiO ₂ nanoparticles (< 100 nm), versus 2.4 mg/m ³ for fine particles (> 100 nm) [15].
Silica nanoparticles	The studies available on the toxicity of nano silica were based on the health effects of silica following exposure via the respiratory tract, after acute or subacute exposure. Lung inflammation, granuloma formation and focal emphysema are some of the reported health effects [16]

There are three main possible routes of exposure to nanomaterials in the workplace [2, 3, 6, 17–19]:

- **Inhalation** is the most common route of exposure to airborne nanoparticles in the workplace. Inhaled nanoparticles can deposit in the respiratory tract and the lungs depending on their shape and size. Following inhalation, they may cross the pulmonary epithelium, enter the bloodstream and reach further organs and tissues. Some inhaled nanomaterials were also found to reach the brain via the olfactory nerve.
- **Ingestion** can occur as a result of unintentional hand-to-mouth transfer from contaminated surfaces, or by ingestion of contaminated food or water. Ingestion may occur as a consequence of inhalation of nanomaterials, as inhaled particles that are cleared from the respiratory tract via the mucociliary escalator may be swallowed. Some ingested nanomaterials may cross the intestinal epithelium, enter the bloodstream and reach further organs and tissues.
- **Dermal** penetration is still being investigated [2, 18]. Intact skin seems to be a good barrier against the uptake of nanomaterials [20]. Damaged skin seems to be less effective, but the level of uptake is likely to be lower than that associated with inhalation [20]. However, notwithstanding this, dermal contact should also be prevented and controlled.

The potential for exposure therefore depends mainly on the likelihood of nanomaterials becoming airborne, with powder form or sprays presenting a greater risk potential than suspensions in liquid, pastes, granular materials or composites. In turn, nanomaterials in liquids present a greater risk potential than bound or fixed nanostructures, such as those in a polymer matrix [21].

2.2 Maintenance activities with risk of exposure to nanomaterials

Maintenance workers may be exposed to manufactured nanomaterials in the following situations:

- when using maintenance products containing nanomaterials;
- when maintaining installations in which nanomaterials are involved, for example a production line in which nanomaterials or products containing nanomaterials are used or processed, and when these nanomaterials have, for example, deposited on the surfaces of the installation being maintained; and
- when the maintenance process itself generates nanomaterials, for example grinding or polishing.

Table 2 presents examples of products that maintenance workers may use, handle or process and that contain nanomaterials to which they may be exposed whilst performing their work.

Table 2: Examples of products containing nanomaterials used in maintenance

Main types of nanomaterials	Examples of products used in maintenance
Titanium dioxide (TiO ₂)	Paints, antibacterial coatings, cleaning products, cements, tiles, wall coatings, dirt-repellent coatings for windows, car coatings (all these products exploit the sterilising, deodorising, anti-fogging and self-cleaning properties of TiO ₂ at the nanoscale); and in glass for its property of changing colour when exposed to light [6, 22–24]
Silica (SiO ₂)	Paints, concrete and cleaning products [6, 23]
Silver nanoparticles	Used as biocides in dyes/paints and varnishes, polymers, sinks and sanitary ceramics, as well as various 'consumer' applications such as disinfectants and cleaning agents [6]
Carbon nanotubes	Paints [23], lightweight constructions
Carbon black	Pigments
Carbides (e.g. WC, TiC, SiC), nitrides (e.g. TiN, CrN), metals (e.g. W, Ti, Mo) or ceramics (e.g. Al ₂ O ₃ , Cr ₂ O ₃)	Tribological coatings applied to the surface of a component in order to control its friction and wear [25]
Iron oxides	Additives in adhesive; formulations to allow for bonding and debonding on command [25]
Zirconium dioxide	Cement additives, plastics additives
Copper oxides	Wood preservatives
Gold nanoparticles	Automobiles and lubricants [26]

Some of the maintenance activities that could result in workers being exposed to nanomaterials include:

- **Use of liquid products containing nanomaterials:**
 - o manipulation of liquid products (e.g. lubricants, paints, coatings, adhesives) or the clean-up of spillages, which can result in dermal exposure of unprotected skin;
 - o in some circumstances maintenance activities involve the preparation of liquid products and this may include pouring or mixing operations in which a high degree of agitation is involved, thus creating aerosols which may be inhaled (and then partly ingested) or deposited onto unprotected skin, resulting in dermal exposure;
 - o spraying, for example of an insulating nanocoating or nanopaint, may result in inhalation, ingestion or dermal exposure; and
 - o spraying liquid combustible nanomaterial also increases the risk of explosion or fire.
- **Use of powders of nanomaterials:**
 - o Handling (e.g. weighing, pouring or blending) nanomaterial-containing powders, in order to prepare products necessary for maintenance activities, may generate airborne nanomaterials and lead to dermal exposure, inhalation and ingestion of nanomaterials.

- **Use of bound or fixed nanostructures (polymer matrix):**
 - Machining, sanding, drilling or any other activities that may damage the matrix structure can result in the release of nanoparticles into the air, which can result in dermal penetration, inhalation or ingestion of nanoparticles. The nanomaterials contained in the matrix being abraded are not necessarily released as primary particles as they may bind onto other particles of the aerosol generated through the process; however, it is possible that these bound nanomaterials become unbound from aerosol particles once inhaled and are therefore released in the body.
- **Maintenance of equipment used to produce or process nanomaterials or products containing nanomaterials:**
 - may release nanomaterials, in some cases accidentally, with possible risk of dermal exposure, inhalation and ingestion.
- **Cleaning of dust collection systems used to capture nanomaterials:**
 - may expose workers to highly concentrated deposited or airborne nanomaterials, which can result in dermal exposure, inhalation and ingestion.
- **Cleaning-up of spills of nanomaterials:**
 - can result in dermal exposure, inhalation and ingestion.
- **Transportation and disposal of waste material containing nanomaterials:**
 - can result in dermal exposure, inhalation and ingestion.

In addition, the dispersion of nanopowders in the air increases the risk of explosion or fire.

The level of exposure will increase if the activities are performed in confined spaces, such as tanks, without proper control measures.

3 Prevention

According to EU Directive 89/391/EEC [5], employers must conduct regular workplace risk assessments and put in place adequate prevention measures. This also applies to the potential risks of nanomaterials in the workplace. In addition, Directive 98/24/EC on chemical agents at work [27] imposes more stringent provisions on the management of risks from substances at work, which also apply to nanomaterials as these fall within the definition of 'substances'. In addition, if a nanomaterial, or the macro-scale material of the same composition, is carcinogenic or mutagenic, Directive 2004/37/EC on carcinogens and mutagens at work [28] has to be fulfilled. In any case, national legislation may have stricter provisions and should be checked.

As nanomaterials are considered to be substances, the REACH (Registration, Evaluation and Authorisation of Chemicals) regulations [29] and the CLP (Classification, Labelling and Packaging of Substances and Mixtures) regulations [30] are equally relevant.

3.1 Challenges for the prevention of nanomaterial risks in maintenance

Carrying out the workplace risk assessment of nanomaterials may, in general, be challenging because of the current limitations linked to:

1. limited knowledge of the hazardous properties of nanomaterials;
2. limitations of the methods and devices available to identify nanomaterials and the sources of emission as well as to measure exposure levels; and
3. lack of information on the presence of nanomaterials, in particular in mixtures or articles as well as down the user chain in which nanomaterials or products containing nanomaterials are used or processed.

Safety Data Sheets (SDSs), which are an important information tool for the prevention of risks from hazardous substances in workplaces, contain, in general, little or no information

about the presence of nanomaterials and their characteristics, risks to workers and prevention [31–34]. This is particularly problematic further down the supply or contracting chain. For example, about 75% of workers and employers in construction are not aware of the presence of nanoproducts at their workplace [35]. Organisations are therefore advised to contact suppliers directly to request additional information. A number of helpful databases that identify the commercial products containing nanomaterials are also available [36–38]. In addition, changes in REACH Annex II [39], the legal framework for the SDS, as well as the guidance from the European Chemicals Agency (ECHA) on the SDSs [40], which gives further advice on how to address characteristics of nanomaterials, are expected to improve the quality of the information contained in the SDS.

E-fact n° 72 (<https://osha.europa.eu/en/publications/e-facts/e-fact-72-tools-for-the-management-of-nanomaterials-in-the-workplace-and-prevention-measures>) introduces available guidance and tools to help manage the risks of nanomaterials in the current context. However, there may be specific additional challenges with regards to managing the risks of nanomaterials and protecting workers in relation to maintenance work.

Subcontracting of maintenance work is very common. Contractors frequently perform their work in facilities they are not familiar with, and, if they have not been properly informed, they may be exposed to nanomaterials without even being aware of it. A lack of information about the nanomaterials that could be present in machines (e.g. in production lines in which nanomaterials or products containing nanomaterials are used or processed), equipment (e.g. exhaust extraction systems) or buildings (e.g. surfaces painted with nanomaterial-containing paints) to be maintained makes it difficult to assess and prevent the risks adequately. Such situations are mainly the result of poorly planned activities, poor work organisation and poor communication up and down the contracting chain.

Another challenge is linked to the fact that maintenance situations often imply abnormal operating conditions and use of equipment. Risk control measures are in some cases disabled because of the maintenance work being performed, for example when opening a closed system to allow access of workers to maintain a machine producing or processing nanomaterials, or when it is the technical risk control device itself that is being maintained. The guidelines available for the prevention of OSH risks from nanomaterials generally address normal operating conditions, but workers' exposure under these 'abnormal' operating conditions during maintenance work could be significantly different. If adequate control measures are not in place during the maintenance work, this of course puts maintenance workers at risk, but also possibly the workers of the client company.

Potential occupational risks associated with nanomaterials must be properly identified, assessed and communicated before scheduling and carrying out (subcontracted) maintenance work [41]. It is important that maintenance workers are properly informed about the presence, characteristics, possible risks and adequate prevention measures in relation to nanomaterials being used, handled or processed in the workplaces where they have to perform maintenance work - as well as in relation to any other workplace hazards. Adequate training and work instructions for workers are also essential.

3.2 Prevention measures

The choice of prevention measures should be based on the workplace risk assessment and should follow the hierarchy of control measures, giving priority to elimination and substitution, followed by technical measures at source, organisational measures and, finally, personal protective equipment as a last resort. In the case of uncertainties on the risks of nanomaterials, the precautionary principle should be applied in the choice of prevention measures to avoid exposure.

3.2.1 Elimination and substitution

Possibilities to eliminate or substitute hazardous nanomaterials should be explored with the company for which the maintenance work is to take place. If maintenance is being carried out at workplaces where nanomaterials are generated or used for the benefits brought by their specific nano-properties, or if maintenance is being done on existing building structures already containing nanomaterials, elimination and substitution may not be an option. However, the balance between the desired properties and effects, on the one hand, and health risks, on the other hand, should always be borne in mind and elimination and substitution given thorough consideration. In the case of hazardous nanomaterials contained in products used, for example, for cleaning or repair, the availability of less hazardous alternatives should be assessed.

In any case, any forms of nanomaterials that may become airborne (such as powders) should be substituted by solubilised or liquid forms, granulates, pastes, or nanomaterials bounded into solids, and the use of powders should be avoided wherever possible.

It may also be possible to reduce the hazardous behaviour of a nanomaterial by modifying it, for example by coating it in order to adjust the dustiness, solubility and other properties.

Specific web-based information tools, such as Stoffenmanager [42] or GISBAU [43], can be used to identify substitution options.

3.2.2 Engineering controls

Technical prevention measures should be implemented at the source of emission of nanomaterials. The most efficient engineering control at source is containment through the use of closed systems and enclosed installations. Suitable effective local exhaust ventilation systems with a high-efficiency particulate air (HEPA) or ultra-low penetration air (ULPA) filter are also efficient to capture nanomaterials at source in cases where containment is not feasible.

However, in some cases, the maintenance work itself may actually consist of inspecting and repairing these technical controls and the preventive function of these engineering controls may therefore be disabled. For example, when a nanomaterial production vessel (normally a closed system) is opened for maintenance work and the exhaust system is therefore stopped, the maintenance worker must then rely on personal protective equipment (see section 4.4).

Local (mobile) air extraction systems may be particularly helpful to protect workers from exposure during maintenance, for example when removing paints from surfaces, which results in particle formation. The capturing efficiency of local exhaust ventilation systems in the case of nanomaterials is not lower than in the case of the coarse materials. When using mobile air extraction devices, the workers' breathing zones should not be within the air flow between the potential nanomaterial emission source and the exhaust extraction system.

Ventilation systems used to control exposure to nanomaterials must have multi-stage filters with HEPA (H14) or ULPA filters as the final filter. Research conducted on the effectiveness of filter materials for nanoparticles and aerosols showed that, in many cases, traditional filters made of glass fibres and electret filters are effective for nanoparticles and aerosols in general.

In confined spaces, extracted air must be replaced by fresh air.

3.2.3 Organisational measures

Organisational measures play an important role in prevention. Owing to the high variety of maintenance locations and tasks, suitable process planning and other organisational measures are crucial. These include the following:

- Designation of specific areas for carrying out maintenance work through which nanomaterials could be released (either from maintenance products or from the objects to be maintained). These areas should be isolated or separated, for example by walls from other workplaces and clearly indicated with appropriate signs.
- Minimising the number of workers potentially at risk and the duration of exposure to nanomaterials.
- Prohibiting access of unauthorised personnel from the area where the maintenance activity is being carried out, for example putting up signs or cordoning off the area.
- Regular cleaning (wet wiping) of work area where nanomaterials are used or handled.
- Monitoring of air concentration levels, for example in comparison with background levels when no handling of nanomaterials occurs.

As there is currently no standardised approach for the use of safety signs or for the labelling of workplaces or containers with nanomaterials, it is recommended that a diligent approach is taken using existing risk and safety phrases from the EU Regulation on the classification, labelling and packaging of substances and mixtures (CLP) [30] and warning signs to provide adequate, relevant and specific information on any actual or potential health and safety risks from the use and handling of nanomaterials.

Maintenance processes should follow some general principles which apply regardless of whether or not nanomaterials are involved:

- Planning of maintenance work should be based on risk assessment and include worker involvement. If maintenance takes place at workplaces where nanomaterials with unknown toxicity and behaviour are handled, these must be taken into account. Priorities in risk management should be given not only to known risks but also to the assessment and management of nanomaterials at workplaces, where hazard and exposure information is missing, incomplete or uncertain.
- Time pressure should be avoided by planning sufficient time to implement and undertake the maintenance work.
- Sufficient training has to be provided to ensure that maintenance workers have the skills and knowledge to perform the work safely and to protect themselves from exposure to any nanomaterial releases.
- Maintenance instructions and information should always be provided to all maintenance workers, in particular when workers are contracted only for this task and/or are not familiar with chemical risks in general and risks from nanomaterials in particular. This information should also be documented in workplace instructions.
- Taking a precautionary approach to risk prevention for nanomaterials; all measures available should be implemented, in accordance with the hierarchy of prevention measures, to reduce the release of nanomaterials.
- After maintenance is finished, the workplace should be cleaned and the entire maintenance process documented.

Workers who are exposed to hazardous nanomaterials during maintenance work should be included in health surveillance programmes with detailed documentation of the exposure situations.

3.2.4 Personal protective equipment

Personal protective equipment (PPE) should be used as a last resort when exposure cannot be reduced effectively enough with the above-mentioned measures. If PPE is determined to be necessary in the risk assessment, a PPE programme should be designed. A good PPE programme will consist of the following elements: selection of appropriate PPE, fitting, training and maintenance of PPE.

Recommendations with regard to protective equipment against nanomaterials are currently the same as those for preventing exposure to dusts and aerosols or, depending on the type of exposure concerned, dermal exposure [44]. These protection measures are thought to be equally effective for nanomaterials.

The work rate and medical fitness of the PPE user needs to be assessed to make sure that the PPE provides the adequate level of protection and can be used appropriately. Trials carried out on the PPE should ensure that its users are able to carry out their work safely with the PPE on and that it still allows them to use other necessary equipment (e.g. spectacles) or tools simultaneously as required. It should be borne in mind that the level of protection of the PPE may become weaker during simultaneous use of several sets of PPE. Also, additional hazards other than nanomaterials may interfere and reduce the effectiveness of the PPE. Therefore, all workplace hazards need to be taken into account when choosing the PPE. All PPE used should have a CE marking, and be used in accordance with the manufacturer's instructions without any modifications.

Maintenance workers may need to wear PPE that may not be necessary during normal operation at the workplace where the maintenance work is performed. If, for example, a production vessel mixing nanomaterial-containing paints is opened, the worker should wear a respirator with an external air supply to prevent inhalation of nanomaterials. During normal operation, the vessel remains closed and no respiratory protection devices are necessary.

▪ Respiratory protection

If exposure to airborne nanomaterials could not be avoided by means of the prevention measures previously mentioned in sections 4.1 to 4.3, then it is recommended that appropriate respiratory protection for such an exposure situation is used. These could be half- or full-face masks with

P3/FFP3 or P2/FFP2 filters, particle filtering devices with air blower and helmet (TH2P or MH3P), or particle filtering devices with air blower and full or half masks (TM2P and TM3P)⁽²⁾ [45].

HEPA filters, respiratory cartridges and masks with fibrous filtering materials are considered effective for nanomaterials.

The choice of respiratory protection device (RPD) will depend on the:

- type, size and concentration of the airborne nanomaterial;
- assigned protective factor for the RPD (which integrates filtering effectiveness and face–seal fit); and
- working conditions.

The filtration effectiveness of respirators and filters is one important factor when assessing PPE. Other factors, such as face-fit, the length of time it is worn and whether the PPE is properly maintained, can also influence exposure mitigation. With regards to filtering half-face masks, not having a proper seal between the face and mask has been shown to be a dominant risk factor [44]. Exposure reduction should always be regarded as a combination of the filter efficiency and the usage characteristics of the respirator, which is expressed by so-called respirator factors in some EU countries.

In cases in which the respiratory devices do not cover the eyes, eye protection (tight-fitting safety goggles) should also be used.

▪ **Protective clothing**

Non-woven textiles (air-tight materials), such as high-density polyethylene (low dust retention and low dust release), should be preferred over woven ones. It is recommended that the use of protective clothing made with cotton fabrics is avoided [44].

If re-usable protective clothing such as overalls is used, provision should be made for regular laundry and the prevention of secondary exposure. Provision must be made to allow clean overalls and protective clothing coats to be put on and dirty ones removed in a manner that does not contaminate the individuals or the general workplace.

▪ **Gloves**

Gloves are particularly important during maintenance work, as workers are frequently in direct contact with nanomaterials, either from the products they use or from the objects and materials they are maintaining. As for chemicals in general, the effectiveness of protective materials is specific to the characteristics of the nanomaterials. Suppliers' recommendations specific to the nanomaterial, e.g. from the SDS, should be considered. For titanium dioxide and platinum particles, nitrile, latex and neoprene were found to be effective [44]. The thickness of the glove material is a major factor in determining the diffusion rate of the nanomaterial. Therefore, the use of two pairs of gloves at the same time is recommended [46].

However, this does not prejudice the effectiveness of gloves for handling liquids or colloids. The effectiveness of gloves for a specific nanomaterial in the form in which occurs at the workplace (dusts, liquids, etc.) should be specifically checked with the glove supplier.

3.3 Prevention of explosion and/or fire

As a result of their small size, nanomaterials in powder form may present risks of explosion, whereas their corresponding coarse materials may not ⁽³⁾ [47]. Care should therefore be taken when nanopowders are handled or generated, including by grinding, sanding or polishing of materials containing nanomaterials.

Preventive measures for nanomaterials in powder form are essentially the same as those for any other explosive and flammable coarse material and explosive dust clouds, and should follow the

² According to studies, the penetration of P2 filters is 0.2% and of P3-filters is 0.011% of particles for nanoparticles of potassium chloride. Tests with different sizes of graphite particle showed penetration of maximum 8%. This indicates a higher protection from P3 filters, but the results cannot be generalised to all nanoparticles (see [45]).

⁽³⁾ The explosiveness of most organic and many metal dusts increases with decreasing particle size. 500 µm appears to be the upper particle size limit of an explosive dust cloud. At present, no size limit has been determined below which dust explosions can be excluded (see [47]).

requirements in Directive 99/92/EC on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres. These include:

- Handling should, when possible, be limited to specific Ex-zones, and carried out in inert atmospheres.
- Materials should be solubilised by wetting the workplace (prevention of dusts).
- Low-spark equipment and other ignition sources or conditions facilitating electrostatic charging should be removed from the workplace; instead, intrinsically safe equipment (signal and control circuits operating with low currents and voltages) should be used, when possible.
- Dust layers should be removed by wet mopping up.
- Storage of explosive or flammable materials at workplaces should be minimised. Anti-static bags may be used.

3.4 Checking the effectiveness of prevention measures

The risk assessment should be regularly revised and the choice and implementation of risk management measures regularly controlled and checked with regard to their effectiveness. This means ensuring the proper functioning of all protective equipment, such as clean benches or laminar flow booths, and regular inspections of all ventilation equipment and their respective filtering systems. Furthermore, the suitability of PPE should be checked and updated, if necessary.

Additionally, the effectiveness of a risk-reduction measure can be assessed by analysing the concentration of nanomaterials in the air before and after the prevention measure. The exposure levels measured when risk management measures are applied should not significantly differ from background concentrations, when there is no source of manufactured nanomaterials. Other indirect measurements for the effectiveness of technical preventative measures can also be applied, such as smoke tests and/or control velocity measurements.

Occupational exposure limit values (OELs) for nanomaterials ⁽⁴⁾ [48] may be developed in the future; however, exposure minimisation should be the primary goal of workplace risk management, and therefore meeting OELs is not sufficient.

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